NONLINEAR EFFECTS IN SEA SEDIMENTS

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Shallow water acoustics

LONG-TERM GOALS

The long-term goals are to understand nonlinear acoustic behavior of porous sediments, to develop theoretical model of propagation and dissipation of acoustic waves in the nonlinear porous sediments, and to utilize the gained knowledge for the practical applications.

SCIENTIFIC OBJECTIVES

a) Develop the nonlinear acoustic theory of poroelastic media using Biot's semilinear model and physical model of contact nonlinearity,
b) Measure the nonlinear parameter of sediments in laboratory tank,
c) Study the effect of sediment parameters (grain size distribution, free gas content, porosity) on nonlinear acoustic properties of the sediments,
d) Evaluate the nonlinear absorption and distortion of sound waves traveling in nonlinear porous medium.

APPROACH

The theoretical approach is based on Biot's semilinear model of poroelastic media. This model assumes that liquid and solid matter of the porous medium exhibit linear behavior within a wide practical range of stresses, while nonlinearity is caused by changes in grain contact areas, cracks closures, etc. An important feature of the proposed approach is the introduction of the dependence of the structural geophysical parameters and the nonlinear parameters of the medium on its porosity. The presence and effect of the third phase (free gas) is also included in the model by introducing gas void dependent bulk modulus of liquid. The derived nonlinear equation of motion can be solved using the slow-varying amplitude assumption and perturbation technique. The derived model establishes quantitative relationships between the measurable effective nonlinear parameter of the porous medium and its geophysical parameters.

The laboratory experimental approach is based on the measurements of the harmonic distortion of the acoustic signal scattered by a small amount of sediment contained in a sound transparent vessel. The container with sediment is placed inside an experimental tank and exposed to harmonic acoustic pressure. Nonlinearity of the sediment causes the generation of higher harmonics which are radiated into surrounding water and measured

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with a hydrophone. The grain size distribution, gas void content, porosity, and density of the tested sediment are also measured in order to establish quantitative relationship between the acoustic nonlinearity and the physical parameters of the medium.

WORK COMPLETED

A set of nonlinear equations of motions using second-order approximation was derived and an analytical solution for amplitude of the second harmonic wave in case of non-dissipative porous media was obtained. The contribution of the slow and fast longitudinal waves in the nonlinear solution were analyzed. The theory was further developed to take into account the third phase (free gas). The developed model establishes relationships between a measurable nonlinear parameter and structural parameters of the porous sediments.

The laboratory experimental study has been directed toward measurements of the nonlinear parameter of sediments and correlation this measurements with the developed theory. The measurements covered wide range of frequencies: from as low as 100 Hz to as high as 100 kHz. In the frequency range 0.1 - 5 kHz relatively low excitation amplitudes (200 Pa) were applied. A small amount of sediment (up to 100 cm^3) was suspended in a water column in a spherical sound transparent vessel and exposed to harmonic acoustical pressure. The vessel was also attached to a precision scale in order to measure weight of the suspended sediments. This allows for measurements of free gas trapped inside the sediments. As the trapped gas releases or dissolves, the increase of the sediment weight is recorded, so the gas void fraction can be determined. The grain size distribution of the sediments was also determined during these measurements. It was found that the nonlinear acoustic response of the sediments depends on both the grain size and especially the amount of trapped air. Very significant levels of nonlinear distortion was observed even for a relatively low amplitude of the excitation signal (under 200 Pa). In some cases (coarse sand with 0.01-0.03 gas void fraction) up to twenty harmonics were observed, with the second harmonic attaining 30% (-10dB) of the fundamental. The estimated values of the effective nonlinear parameter were enormously high (up to 10^8) and cant be explained by the air bubble nonlinearity alone.

In the frequency range 40 -100 kHz the applied pressure amplitude was increased up to $5 \cdot 10^4$ Pa on some frequencies. The sediments were placed on the bottom of the tank in order to create a flat reflective surface. High levels of nonlinear distortion were also observed in the signal reflected from the air contained sediments, where the effective nonlinear parameter was about 500.

The results of these measurements were compared with the computational results using the developed theory. The measurements were in very good agreement with the theoretical calculation for high frequency range (40-100 kHz), however in the low frequency range the experimentally determined value of the nonlinear parameter was much higher than predicted, so the further investigation of this phenomenon is required.

RESULTS

The nonlinear equations of motion for fluid-saturated poroelastic media has been derived based on Biot‗s semilinear model. The nonlinear solution for non-dissipative medium has been obtained and analyzed. The developed theory has been extended for three-phase medium (fluid-gas-solids). The relationship between the effective nonlinear parameter of the porous medium and its geophysical parameters has been introduced.

Significantly high acoustical nonlinearity was observed for water-saturated sediments with a small amount of trapped gas.

Good agreement between the developed nonlinear theory and experimental data was demonstrated for high frequency acoustic waves, while the low frequency range data needs further examination.

IMPACT/APPLICATION

It is anticipated that the obtained result will stimulate wider interest in nonlinear acoustic phenomena in sediments and other poroelastic media. The observed high level of nonlinearity may have a great impact on scattering and propagation of acoustic waves in sediments. On the other hand, the notable nonlinear effects can be used for the purpose of sediment characterization.

RELATED PROJECTS

The developed theory and the experimental approach is used for measurements and evaluation of the nonlinearity of porous bones. This project is supported by NASA and is aimed to develop a nonlinear acoustic method of human bone density monitoring.

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